

AN-483B

Application Note

15 TO 60 WATT AUDIO AMPLIFIERS USING COMPLEMENTARY DARLINGTON OUTPUT TRANSISTORS

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The use of monolithic power darlington transistors can simplify the design of high-fidelity power amplifiers. Circuit and performance information are provided to facilitate the design of 15 watt to 60 watt amplifiers utilizing the power darlington devices.



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Transistor Q2 is used to forward bias the output darlington devices. Resistors R4, R_V and R1 form a resistive divider which sets the collector to emitter voltage of Q2 at approximately 2.4 V for biasing of the output. R_V is made variable so that the I_C of Q2 can be adjusted and consequently the dc "idle current" in the output transistors can be set to minimize cross-over distortion. Twenty milliamps of idle current is sufficient to eliminate this distortion.

To ensure maximum swing during peak negative signal excursions, R6 is connected to the speaker side of the output coupling capacitor. This makes use of the dc charge on the output coupling capacitor to provide drive current to the base of Q4 thru R6 (bootstrapping).

THE 15-60 WATT AC COUPLED CIRCUIT

$$\frac{V_{BE(on) Q2}}{R_4} \approx \frac{0.6}{1.8 \text{ k}\Omega} = 0.33 \text{ mA}$$
$$A_V = \frac{R_6}{R_5}$$

Transistor Q2 has approximately 60 dB of voltage gain and determines the dominant pole in the amplifier. A 50 pF capacitor is used in this stage to compensate the amplifier to prevent high frequency oscillations.

A constant current source, Q4, is used to eliminate the need for bootstrapping the base of Q6. This eliminates the effects of the bootstrap capacitor on frequency, providing



TABLE II — Parts List of 15 to 60 Watt Circuit of Figure 2

| Power Watts (RMS) | 15 | | 20 | | 25 | | 35 | | 50 | | 60 | |
|---|-------------|-------------|-------------|-------------|-------------|-------------|------------|------------|------------|------------|------------|------------|
| Load Impedance | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 |
| V _{CC} | 32 V | 38 V | 36 V | 46 V | 38 V | 48 V | 44 V | 56 V | 50 V | 65 V | 56 V | 72 V |
| R5 (ohms) | 620 | 510 | 560 | 470 | 560 | 390 | 470 | 330 | 390 | 270 | 330 | 220 |
| R7 (ohms) | 33 k | 39 k | 39 k | 47 k | 39 k | 47 k | 47 k | 56 k | 47 k | 68 k | 56 k | 68 k |
| Q1 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A06 | MPS A05 | MPS A06 | MPS A06 | MPS A06 |
| Q2 | MPS A55 | MPS A55 | MPS A55 | MPS A55 | MPS A55 | MPS A55 | MPS A55 | MPS A56 | MPS A55 | MPS A56 | MPS A56 | MPS A56 |
| Q3 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 |
| Q4 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A06 | MPS A05 | MPS A06 | MPS A06 | MPS A06 |
| Q5 | MJE 1100 | MJE 1100 | MJE 1100 | MJE 1100 | MJE 1102 | MJE 1100 | MJ 3000 | MJ 1001 | MJ 3000 | MJ 3001 | MJ 3001 | MJ 3001 |
| Q6 | MJE 1090 | MJE 1090 | MJE 1090 | MJE 1090 | MJE 1092 | MJE 1090 | MJ 2500 | MJ 901 | MJ 2500 | MJ 2501 | MJ 2501 | MJ 2501 |
| Voltage rating on C1 | 35 V | 40 V | 40 V | 50 V | 40 V | 50 V | 45 V | 60 V | 50 V | 65 V | 60 V | 75 V |
| Voltage rating on C2, C3 | 20 V | 25 V | 25 V | 30 V | 25 V | 30 V | 25 V | 35 V | 30 V | 35 V | 35 V | 40 V |
| Voltage rating on C4 | 40 V | 45 V | 45 V | 55 V | 45 V | 55 V | 50 V | 65 V | 60 V | 75 V | 65 V | 80 V |
| Min. heat sink for outputs @ 55°C ambient temper- ature and 10% high line voltage | 9.5°C/W | | 7.0°C/W | | 5.0°C/W | | 6.0°C/W | 5.5°C/W | 4.0°C/W | | 3.0°C/W | |

TABLE III — Typical Performance of Circuit in Figure 2

| | |
|--|---------------------|
| Idle Current (Adjusted with R _V) | 20 mA |
| Input Impedance | 50 k Ω |
| Nominal Input Sensitivity for Rated Power Output | 1.0 Vrms |
| Total Harmonic Distortion at 1.0 kHz and any Power up to Full Rated Output (See Figure 3) | 0.2% |
| Intermodulation Distortion 60 Hz with 2 kHz and 7 kHz Mixed 4:1 at 1/2 Maximum Rated Output Power | 0.2% |
| Frequency Response (-1 dB Points) | 20 Hz and 50 kHz |
| Maximum Safe Operating Frequency at Full Rated Power — 20 Watt Amplifier: 60 Watt Amplifier: | 50 kHz 30 kHz |

lower distortion at low frequencies. The collector-emitter voltage of Q3 is a function of its collector current. Therefore, to eliminate cross-over distortion when a poorly regulated supply is used for V_{CC}, it is necessary to make the current source, Q4, independent of supply voltage variations. Diode D1 is used for this purpose since its forward voltage and, consequently, the voltage across R8 are relatively constant with respect to current changes in D1. Hum and noise from the power supply are filtered out by R1 and C1.

Table II lists the parts used for the 15 to 60 watt circuits. Table III and Figure 3 show typical performance of the amplifier.

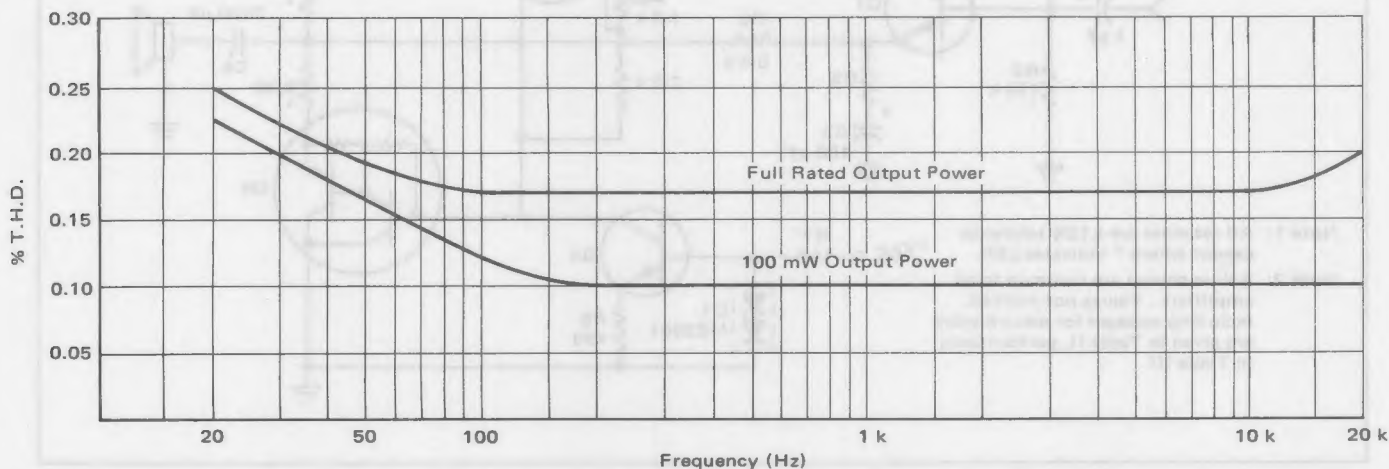


FIGURE 3 — Typical T.H.D. versus Frequency for Amplifier of Figure 2

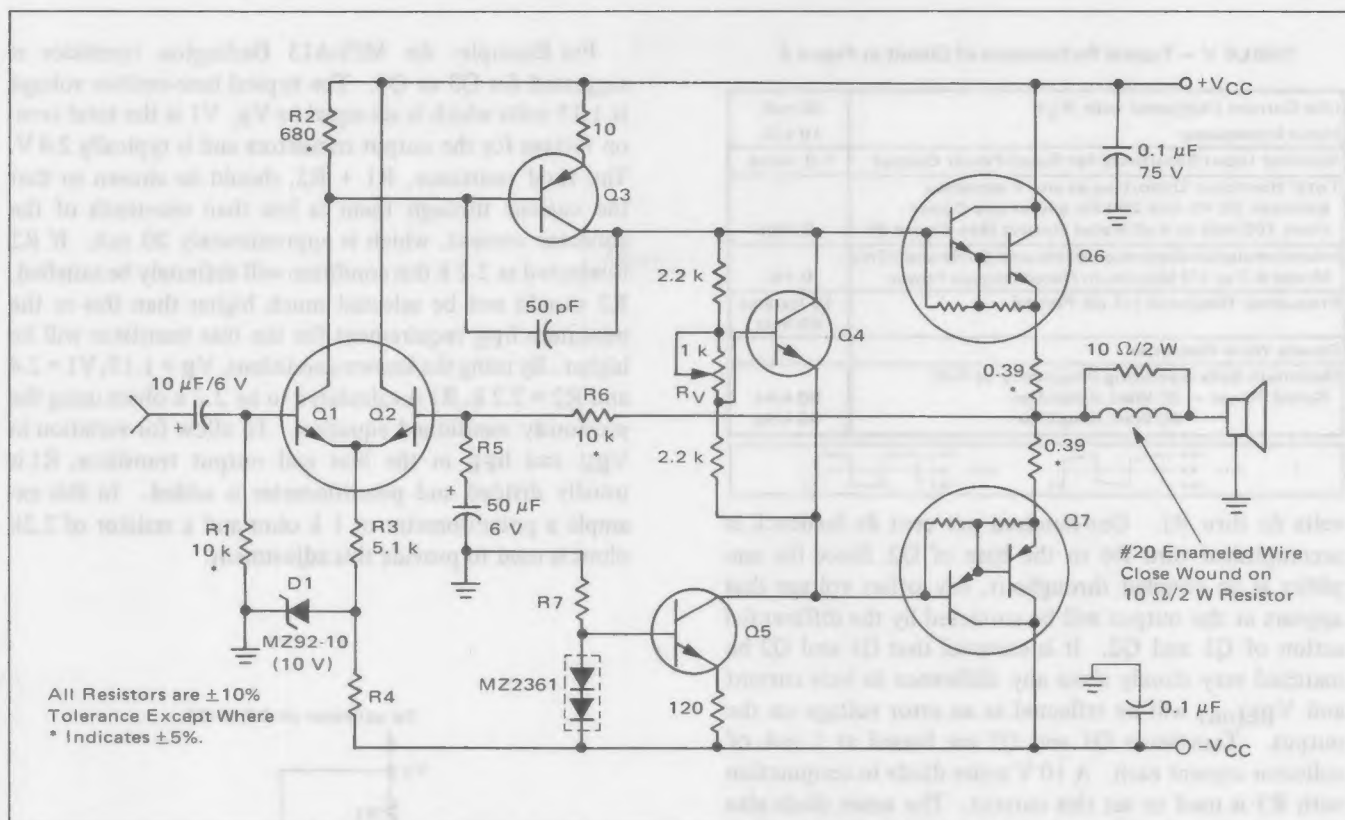


FIGURE 4 – 15 to 60 Watt Power Amplifier with DC Coupled Output

THE 15 TO 60 WATT DC-COUPLED CIRCUIT

The 15 to 60 watt dc-coupled circuit is shown in Figure 4. The output center voltage must be maintained at zero volts dc not only to ensure maximum signal swing but also

to prevent dc from appearing at the speaker. The zero center voltage is obtained by using a split power supply and a differential amplifier on the input of the circuit. The signal input base of the dif-amp (Q1) is referenced to 0

TABLE IV – Parts List for 15 to 60 Watt Circuit of Figure 4

| Power Watts (RMS) | 15 | | 20 | | 25 | | 35 | | 50 | | 60 | |
|---|----------|----------|----------|----------|----------|----------|-----------------|---------|---------|---------|---------|---------|
| Load Impedance | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 |
| V _{CC} | ± 16 V | ± 19 V | ± 18 V | ± 23 V | ± 19 V | ± 24 V | ± 22 V | ± 28 V | ± 25 V | ± 33 V | ± 28 V | ± 36 V |
| R4 (ohms) | 1.5 k | 2.2 k | 2.0 k | 3.3 k | 2.2 k | 3.3 k | 3.0 k | 3.9 k | 3.6 k | 5.6 k | 3.9 k | 6.2 k |
| R5 (ohms) | 1.2 k | 820 | 1.0 k | 750 | 1.0 k | 680 | 820 | 560 | 680 | 470 | 620 | 430 |
| R7 (ohms) | 15 k | 18 k | 18 k | 22 k | 18 k | 22 k | 22 k | 27 k | 22 k | 33 k | 27 k | 33 k |
| Q1,Q2 Dual Transistors | MD 8001 | MD 8001 | MD 8001 | MD 8001 | MD 8001 | MD 8001 | MD 8001 | MD 8001 | MD 8001 | MD 8002 | MD 8001 | MD 8002 |
| Q3 | MPS A55 | MPS A55 | MPS A55 | MPS A55 | MPS A55 | MPS A55 | MPS A55 | MPS A56 | MPS A55 | MPS A56 | MPS A56 | MPS A56 |
| Q4 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 | MPS A13 |
| Q5 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A05 | MPS A06 | MPS A05 | MPS A06 | MPS A06 | MPS A06 |
| Q6 | MJE 1100 | MJE 1100 | MJE 1100 | MJE 1100 | MJE 1102 | MJE 1100 | MJ 3000 | MJ 1001 | MJ 3000 | MJ 3001 | MJ 3001 | MJ 3001 |
| Q7 | MJE 1090 | MJE 1090 | MJE 1090 | MJE 1090 | MJE 1092 | MJE 1090 | MJ 2500 | MJ 901 | MJ 2500 | MJ 2501 | MJ 2501 | MJ 2501 |
| Min. heat sink for outputs @ 55°C ambient temperature and 10% high line voltage | 9.5°C/W | | 7.0°C/W | | 5.0°C/W | | 6.0°C/W 5.5°C/W | | 4.0°C/W | | 3.0°C/W | |

TABLE V — Typical Performance of Circuit in Figure 4

| | |
|--|------------------|
| Idle Current (Adjusted with R_V) | 20 mA |
| Input Impedance | 10 k Ω |
| Nominal Input Sensitivity for Rated Power Output | 1.0 Vrms |
| Total Harmonic Distortion at any Frequency Between 20 Hz and 20 kHz and at any Power from 100 mW to Full Rated Output (See Figure 5) | 0.15% |
| Intermodulation Distortion 60 Hz with 2 kHz and 7 kHz Mixed 4:1 at 1/2 Maximum Rated Output Power | 0.1% |
| Frequency Response (-1 dB Points) | 10 Hz and 30 kHz |
| Square Wave Response | * |
| Maximum Safe Operating Frequency at Full Rated Power — 20 Watt Amplifier: | 50 kHz |
| 60 Watt Amplifier: | 30 kHz |

volts dc thru R1. One-hundred per cent dc feedback is accomplished thru R6 to the base of Q2. Since the amplifier is dc coupled throughout, any offset voltage that appears at the output will be corrected by the differential action of Q1 and Q2. It is essential that Q1 and Q2 be matched very closely since any difference in base current and $V_{BE(on)}$ will be reflected as an error voltage on the output. Transistors Q1 and Q2 are biased at 1 mA of collector current each. A 10 V zener diode in conjunction with R3 is used to set this current. The zener diode also provides filtering to prevent hum and noise on the $-V_{CC}$ line from getting into the input stage. The value of R4 is chosen for 4 mA; 2 mA of current for the zener diode and the diff amp's 2 mA:

$$R4 = \frac{V_{CC} - 10 \text{ V}}{4 \text{ mA}}$$

The closed-loop ac gain of the amplifier is determined by:

$$A_V = \frac{R6}{R5}$$

The remainder of the circuit operation is identical to the previously described ac coupled approach of Figure 2.

The choke used on the output is to prevent high-frequency oscillations that might occur with capacitive loading.

Table IV lists the parts used for the dc-coupled amplifiers. Table V and Figure 5 show the typical performance of these amplifiers.

OUTPUT STAGE BIASING

The output stage biasing for the circuits in Figures 2 and 4 is controlled by Q3 in Figure 2 and Q4 in Figure 4. Q3 or Q4 should have an h_{FE} greater than 100 so that the current through R1 and R2 can be made less one-tenth of the collector current. If this condition is satisfied the base-emitter drop of Q3 or Q4 can be considered a reference voltage and the values of R1 and R2 can be calculated from

$$\frac{V_1}{V_R} = 1 + \frac{R_1}{R_2} \quad (\text{See Figure 6})$$

For Example: An MPS-A13 Darlington transistor is suggested for Q3 or Q4. The typical base-emitter voltage is 1.15 volts which is set equal to V_R . V_1 is the total turn-on voltage for the output transistors and is typically 2.4 V. The total resistance, $R_1 + R_2$, should be chosen so that the current through them is less than one-tenth of the collector current, which is approximately 20 mA. If R2 is selected as 2.2 k this condition will definitely be satisfied. R2 should not be selected much higher than this or the minimum h_{FE} requirement for the bias transistor will be higher. By using the known conditions, $V_R = 1.15$, $V_1 = 2.4$ and $R_2 = 2.2 \text{ k}$, R1 is calculated to be 2.2 k ohms using the previously mentioned equation. To allow for variation in V_{BE} and h_{FE} in the bias and output transistor, R1 is usually divided and potentiometer is added. In this example a potentiometer of 1 k ohm and a resistor of 2.2k ohms is used to provide this adjustment.

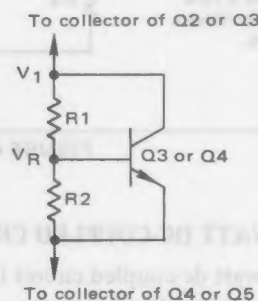


FIGURE 6 — Bias Circuit for Output Stage

OVERLOAD PROTECTION

A circuit for overload protection applying to all the darlington amplifiers discussed in this note, is shown in Figure 7. This circuit holds the darlington output devices within their dc safe-operating area in the event the output is accidentally shorted.

Resistors R1 and R2 form a voltage divider which senses the peak current flowing through the output transistor and R_E . This divider is set to turn Q1 and Q2 "ON" when the output current goes above the maximum normal operating level. When Q1 and Q2 conduct, they limit the amount of drive to the base of the output and, consequently, limit the amount of output current. Transistor Q1 and its associated circuitry function for the positive half of the waveform; Q2 and its associated circuitry, for the negative half of the waveform. Diode D1 prevents the collector-base junction of Q1 and Q2 from being forward biased during normal signal conditions and creating distortion in the output waveform.

During shorted output, the average power dissipation in the output devices increases about four times over the normal operating dissipation. The length of time a shorted

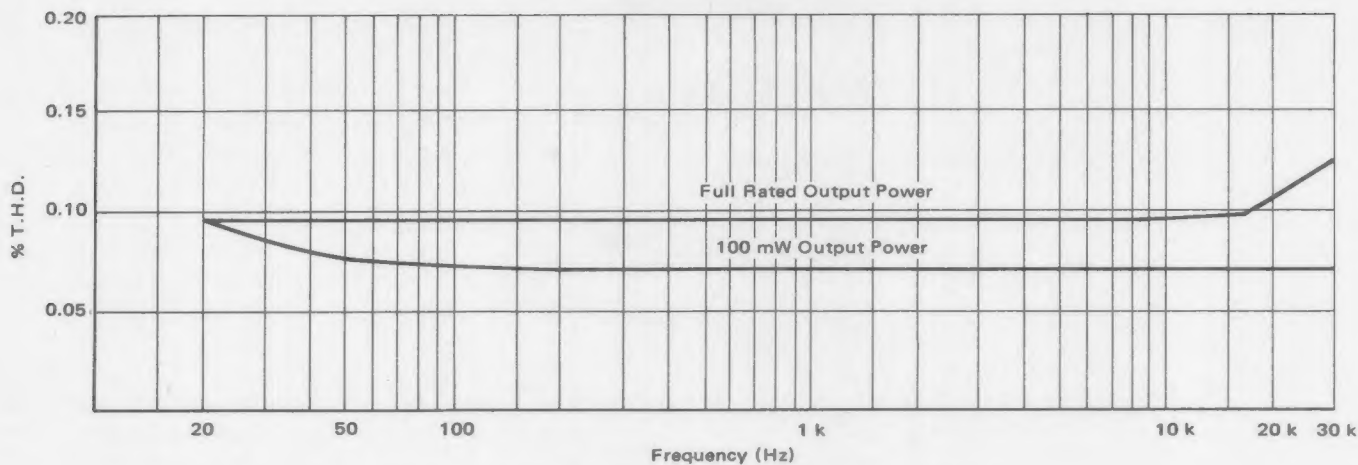


FIGURE 5 — Typical T.H.D. versus Frequency for Amplifier of Figure 4

condition can be tolerated is strictly a function of the size and capability of the output heat sinks. When the minimum heat sinks specified in Tables I, II and IV are used, and the circuit is operated in a 25°C ambient, the output devices can drive a shorted load for a few minutes without any damage. "Load line" protection circuits can also be used with the darlington amplifiers for long term overload protection.

Table VI gives the values of R1 in Figure 7 which, in the event of an overload, provide adequate safe operating area protection on the output devices for all of the amplifiers described in this note.

TABLE VI

| Power Watts (RMS) | Load Impedance (ohms) | Value of R1 (ohms) |
|-------------------|-----------------------|--------------------|
| 15 | 4 | 330 |
| | 8 | 150 |
| 20 | 4 | 470 |
| | 8 | 180 |
| 25 | 4 | 510 |
| | 8 | 220 |
| 35 | 4 | 750 |
| | 8 | 390 |
| 50 | 4 | 910 |
| | 8 | 560 |
| 60 | 4 | 1.0 k |
| | 8 | 620 |

CONCLUSION

This note has described 15 watt to 60 watt audio power amplifiers using silicon monolithic darlington power output transistors.

The circuits illustrate the simplification resulting from the use of these darlington devices. The achievable performance of these amplifiers is equal to that previously obtained using the best silicon discrete devices.

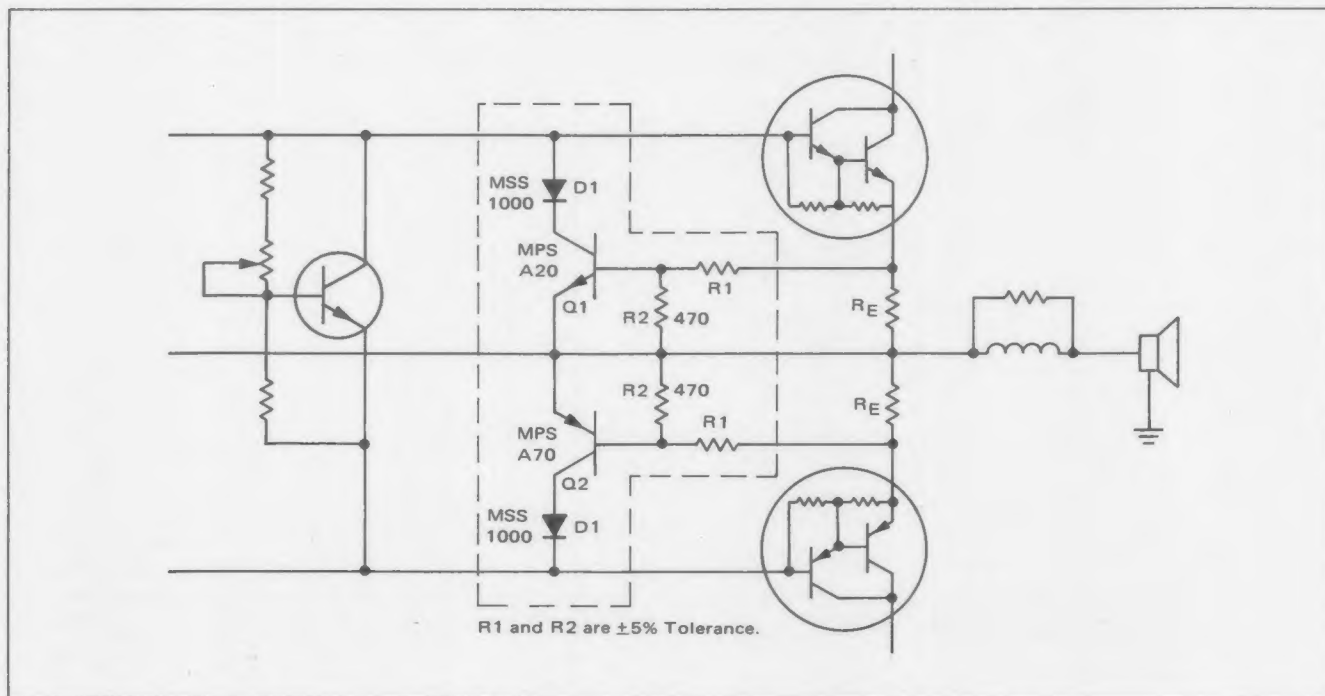


FIGURE 7 — Overload Protection Circuit for Amplifiers of Figures 1, 2 and 3

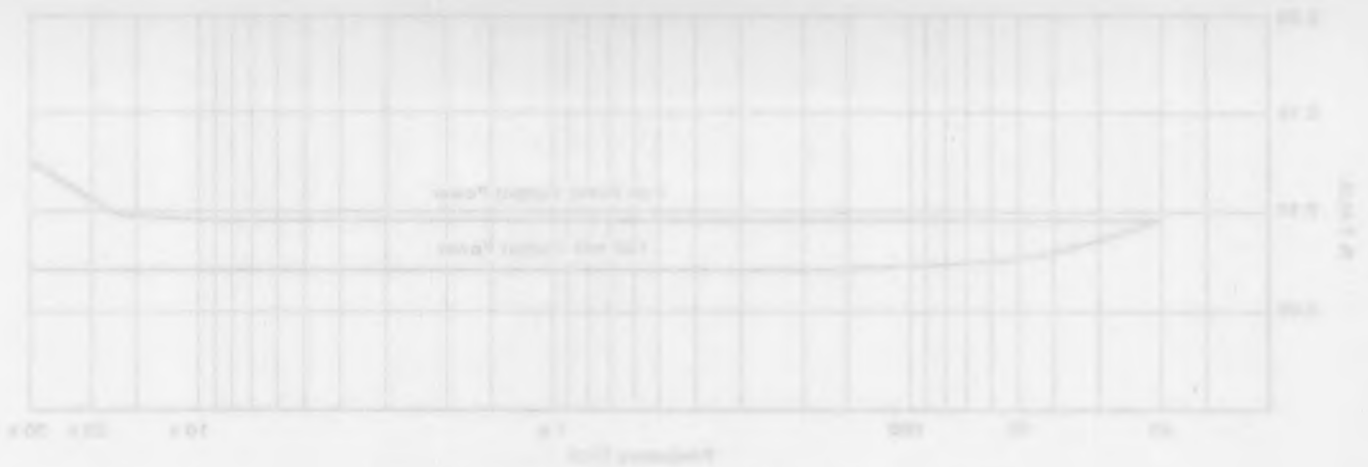


FIGURE 2 - Load Power vs. Frequency for Amplifier 4, Figure 1

TABLE VI

| Power (W) | Load Power (W) | Frequency (Hz) |
|-----------|----------------|----------------|
| 100 | 100 | 0 |
| 90 | 90 | 10 |
| 80 | 80 | 20 |
| 70 | 70 | 30 |
| 60 | 60 | 40 |
| 50 | 50 | 50 |
| 40 | 40 | 60 |
| 30 | 30 | 70 |
| 20 | 20 | 80 |
| 10 | 10 | 90 |
| 0 | 0 | 100 |

The circuit shown in Figure 1 is a typical example of the use of this amplifier. The circuit is designed to provide a constant output power of 100 W over the frequency range of 0 to 100 Hz.

Condition can be achieved by using a constant output power and varying the output frequency. When the output power is constant, the output frequency is constant. When the output power is constant, the output frequency is constant. When the output power is constant, the output frequency is constant.

Table VI gives the values of P_L in Figure 1 which is the result of an overload. Power values are given in the table for the output power for all of the frequencies shown in the table.

CONCLUSION

The circuit has been designed to provide a constant output power of 100 W over the frequency range of 0 to 100 Hz. The circuit is designed to provide a constant output power of 100 W over the frequency range of 0 to 100 Hz.

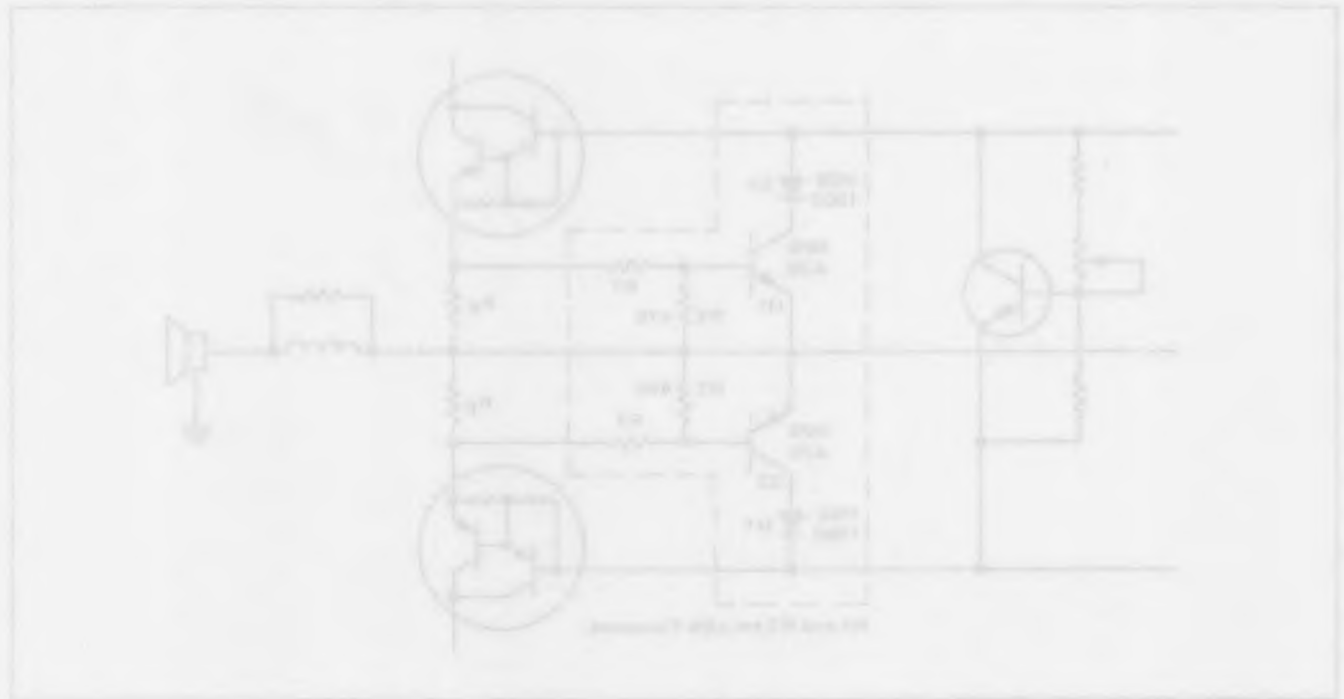


FIGURE 1 - Load Power vs. Frequency for Amplifier 4, Figure 1



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